CCD Radiation Damage Studies

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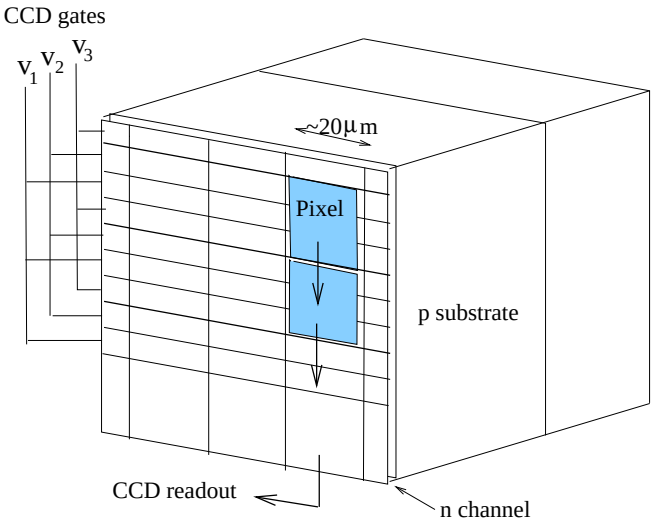
Outline:

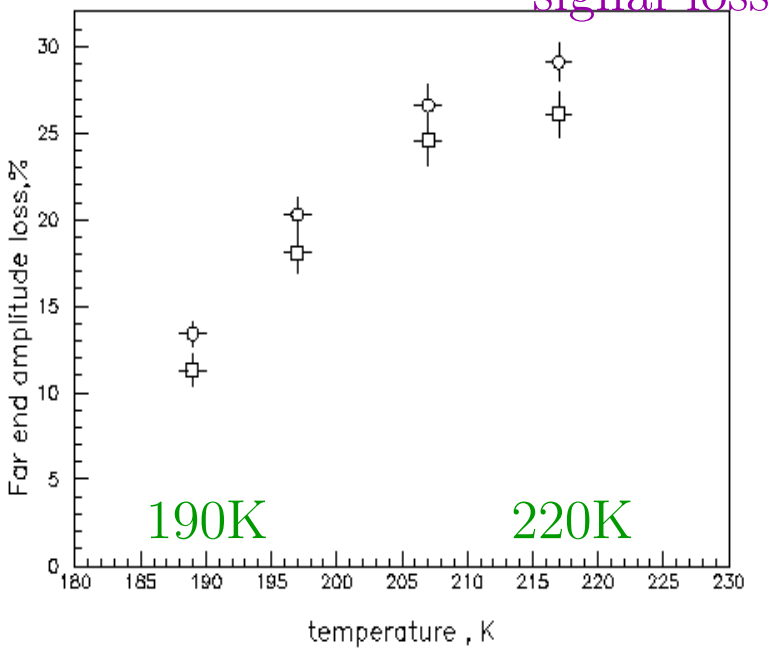
- Introduction
- Neutron and Electron irradiation
- Study of SLD VXD3
- Measurement of the trap filling time
- Conclusions

CCD



The CCD at SLD has shown an outstanding performance, but it also saw the **radiation damage** when undamped beam run through the detector.

signal loss

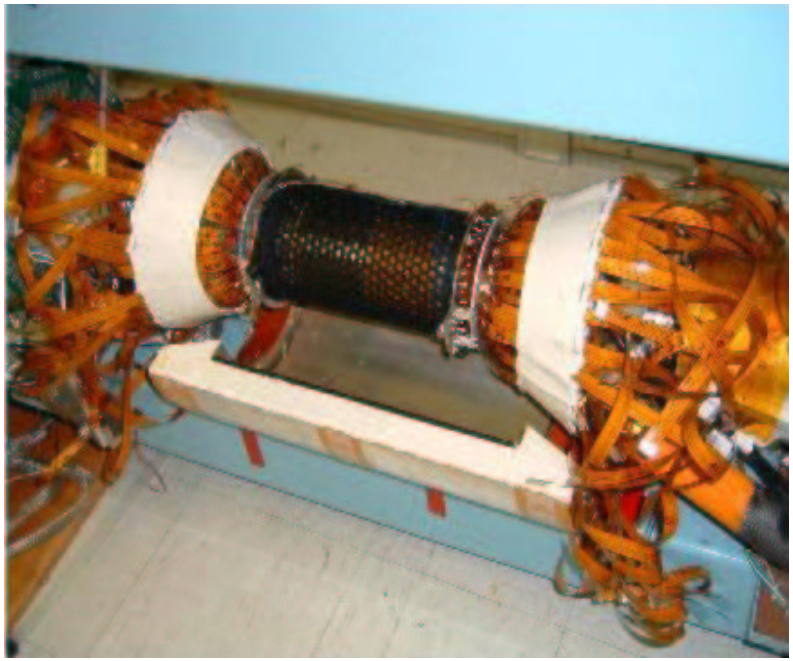


CCD is proposed as vertex detector for next linear collider. It has excellent space resolution ($\sim 4\mu$m) and is very thin (0.4-0.1%X_0).

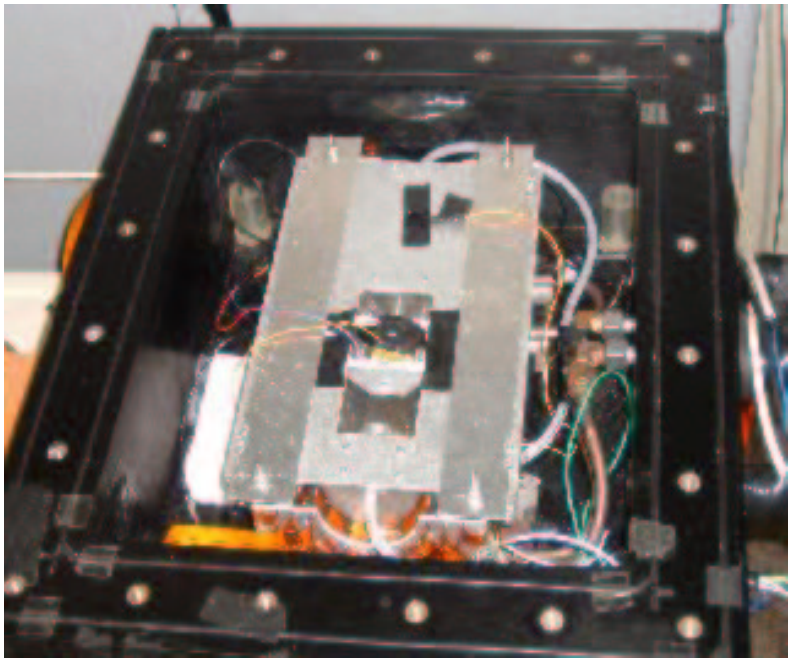
But is it radiation tolerant?

Study SLD VXD3 and spare CCDs

SLD VDX3 detector



CCD test stand



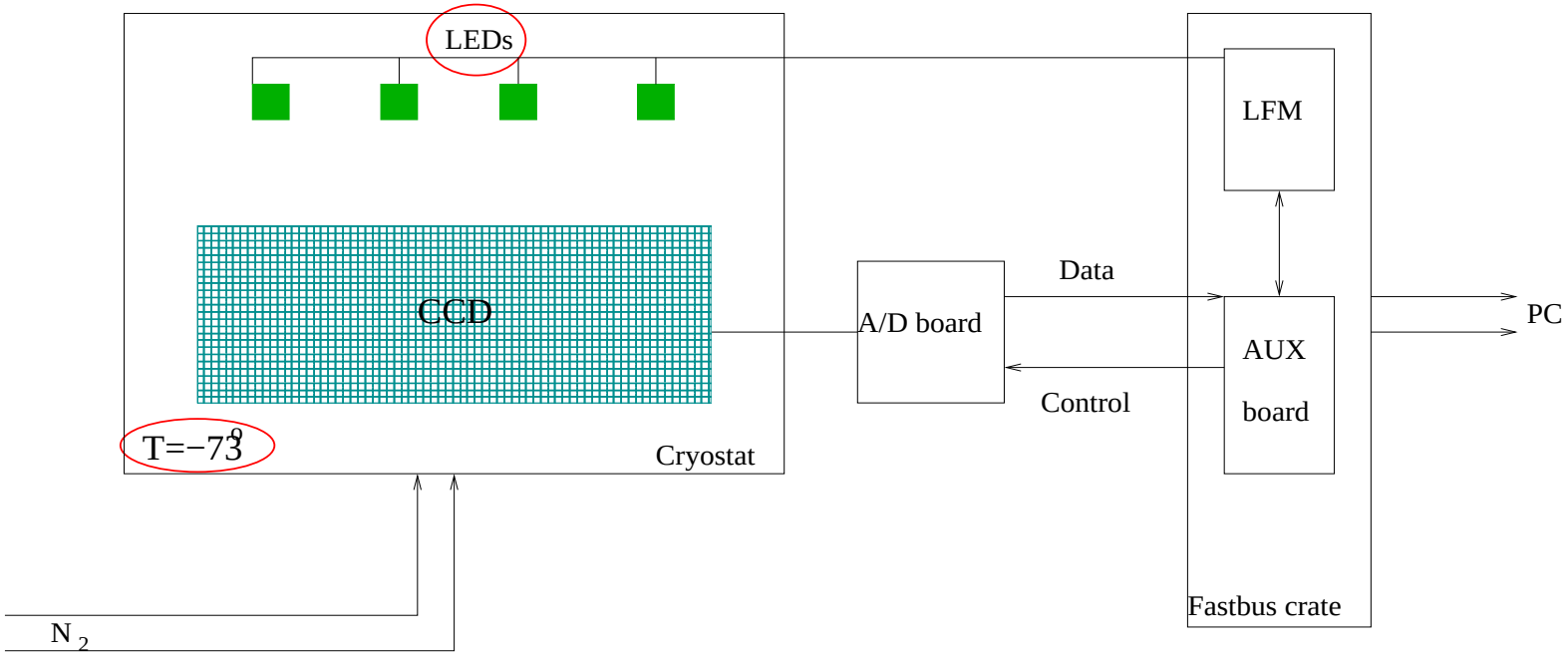
Goals

- predict radiation damage of CCD in the environment of LC
- to verify background conditions (source of radiation) at LC by studying SLD VXD3 CCD
- to minimize impact of radiation damage on the operation

Understand effects of radiation damage
(quantitatively and qualitatively)
by different type of particles (neutrons, electrons).

- 1998 : study of the CCD irradiated with $5 \cdot 10^9$ neutrons/cm^2. (J. Brau, N.Sinev, IEEE Trans. Nucl. Sci. NS-47 (2000) 1898)
- 2003 step 1: study of the CCD irradiated with 10^{12} electrons (60 MeV)/cm^2. (J. Brau, *et al.*, submitted to IEEE Trans. Nucl. Sci.)
- 2003 step 2: combined study of these CCDs and SLD VXD3 (this talk)

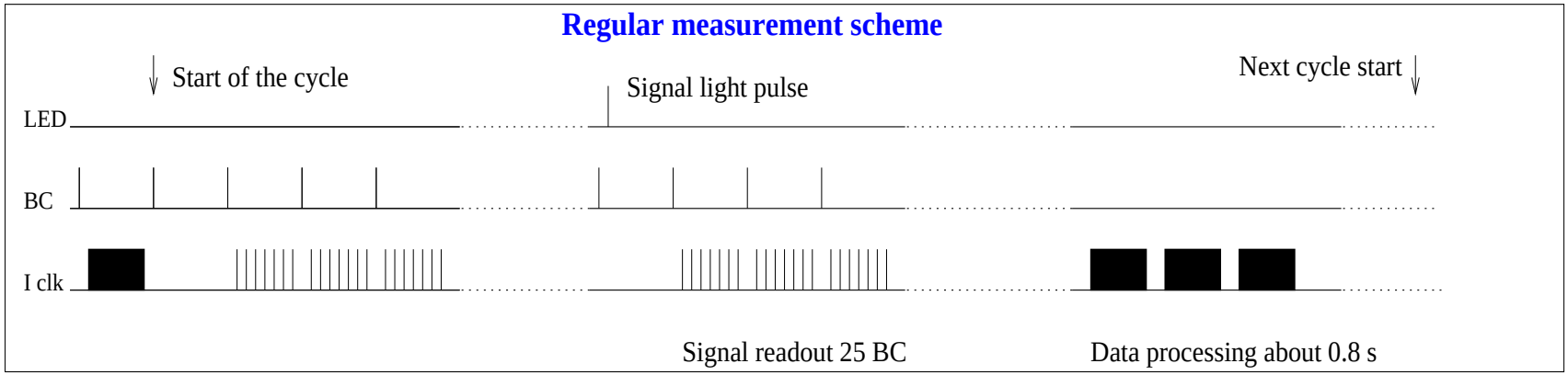
CCD Radiation Damage Test-stand

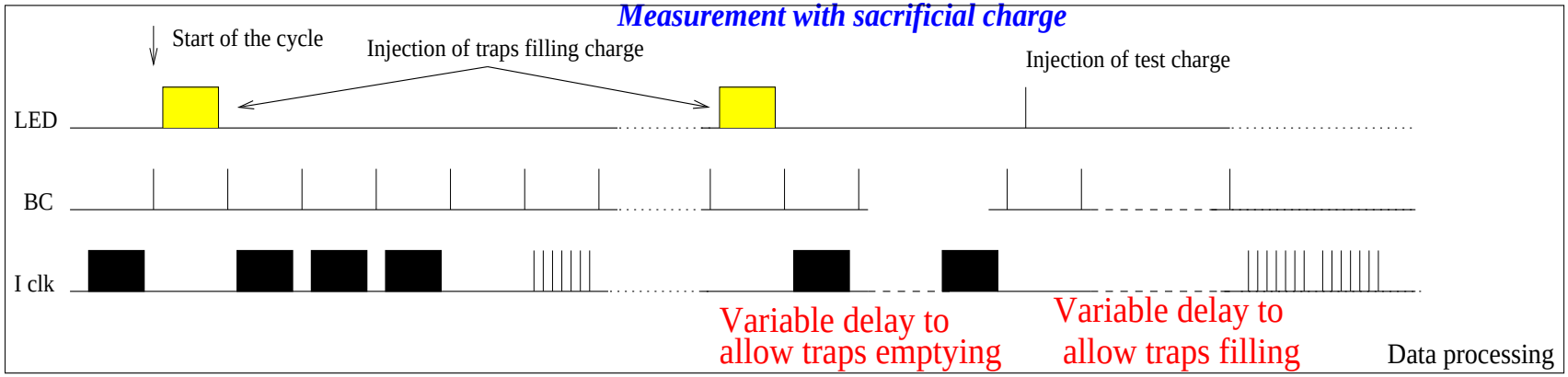


Two types of LED were used :

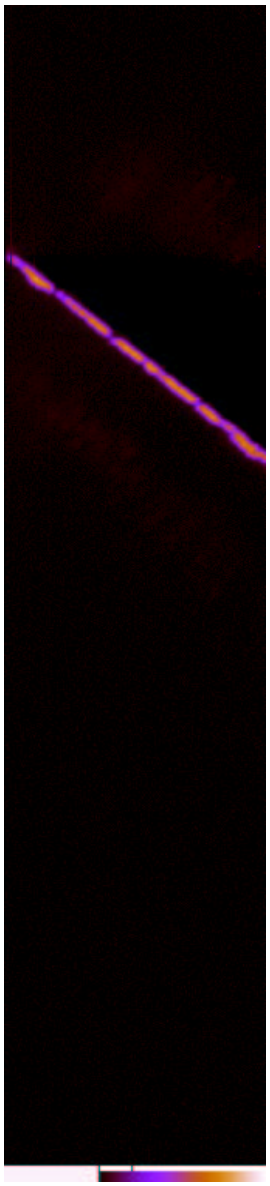
- "Narrow line" source which flashes only few pixels per column. The average signal intensity is about 1000 electrons/pixel
- "Uniform" light source which flashes the complete CCD surface uniformly. The average signal intensity is about 25-30 electrons/pixel

Timing Diagram of the test

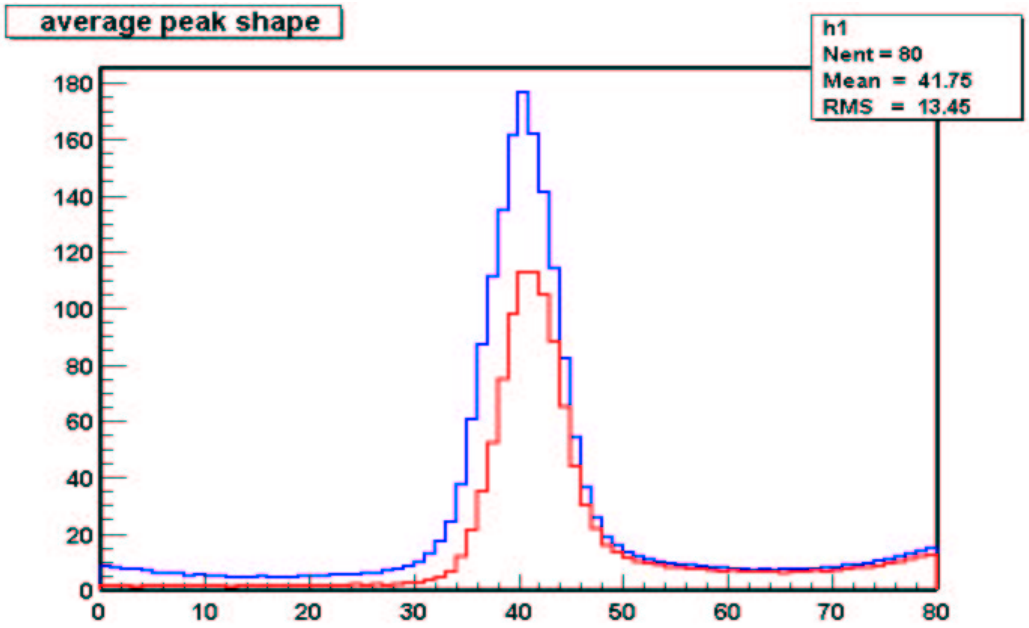




Measurements with narrow light



The method shows integrated number of traps in column



Blue - all traps are filled with sacrificial light

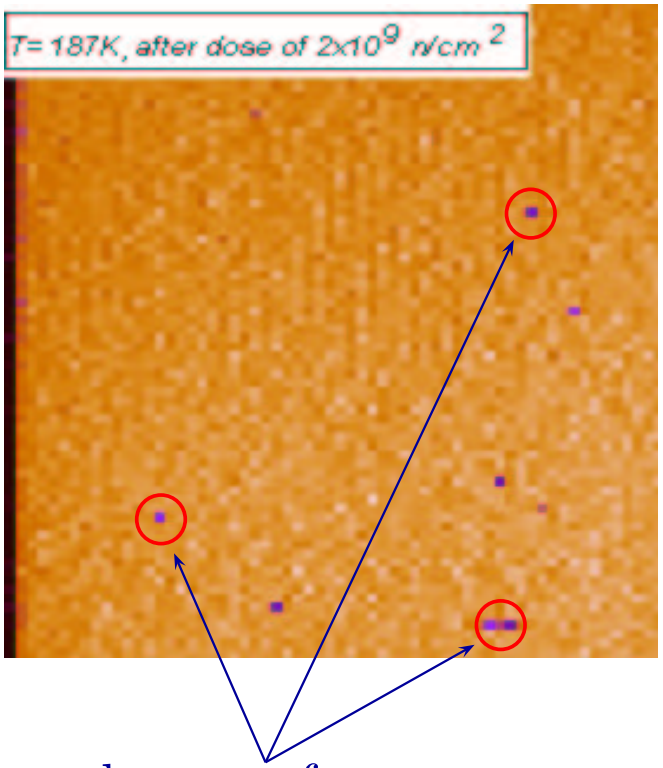
Red - all traps are empty (results in signal loss)

Irradiation by neutrons as well as by electrons result in radiation damage (significant amount of traps are produced).

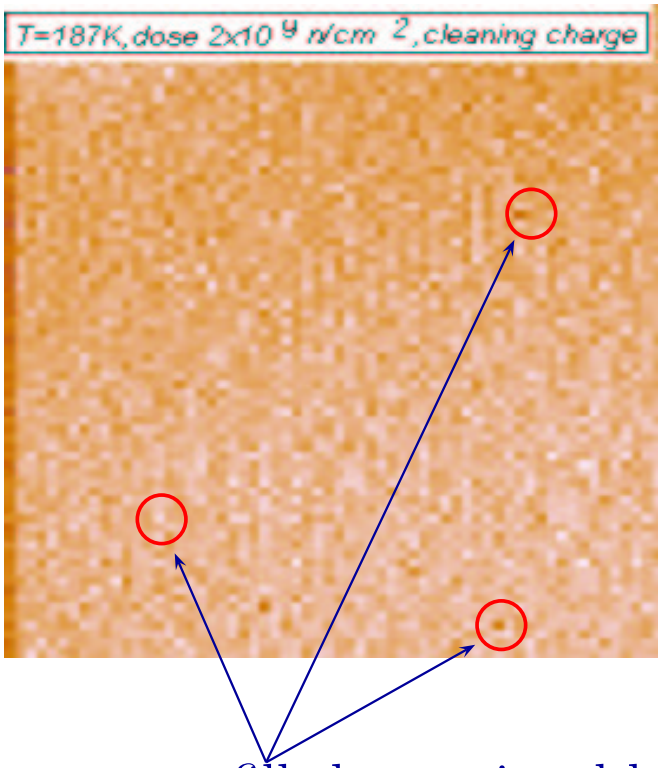
Measurement with Uniform Light

Each pixel is clearly identified

Varying delay between sacrificial light and signal one could have all traps filled or empty



clusters of traps



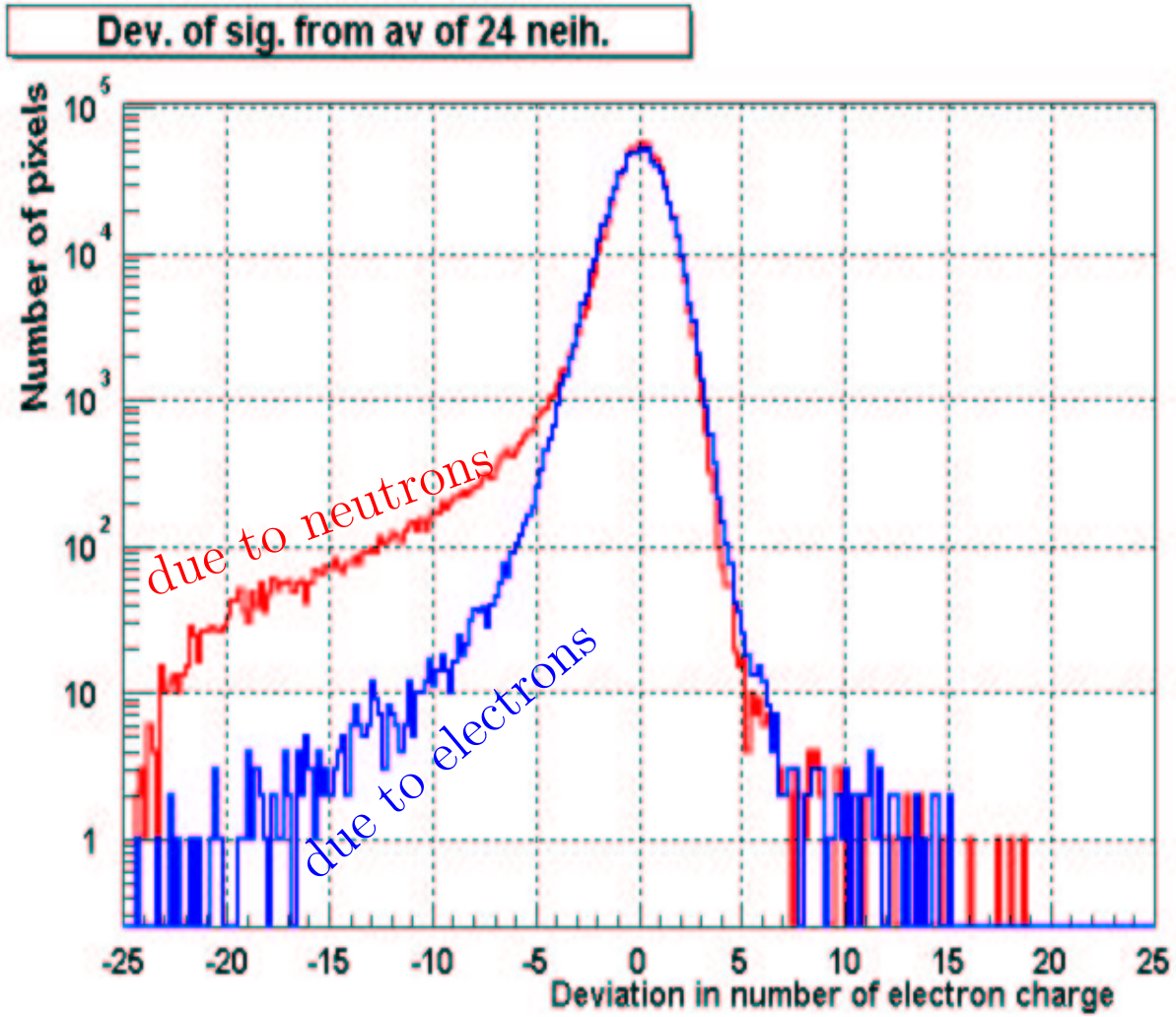
traps are filled - no signal lost

sensitive to the clusters of traps

Comparison of the electron and neutron damage

Using uniform light source the clusters of traps are identified

Damage by neutrons is associated with clusters of traps, while electron irradiation results in few traps distributed uniformly over the surface

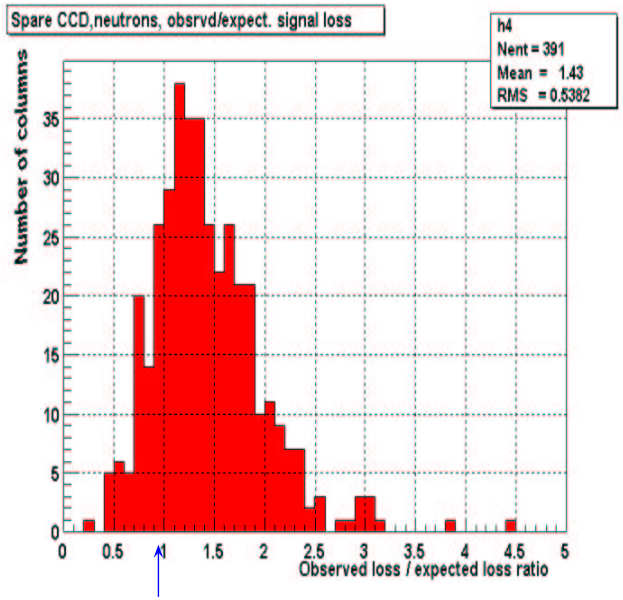


deviation of Ntraps from average

$N_{observed}/N_{expected}$

where $N_{observed}$ is extracted with narrow light method,
while $N_{expected}$ is signal loss estimated from the trap clusters.

After neutron irrad. | After neutron+electron irrad. | VXD3



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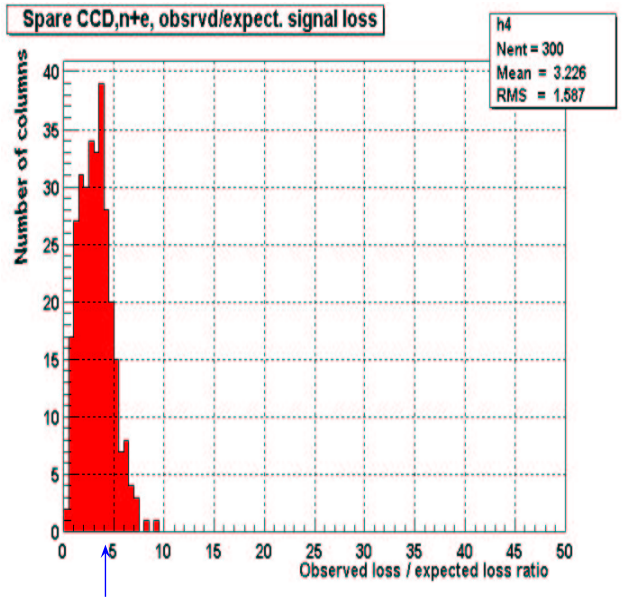

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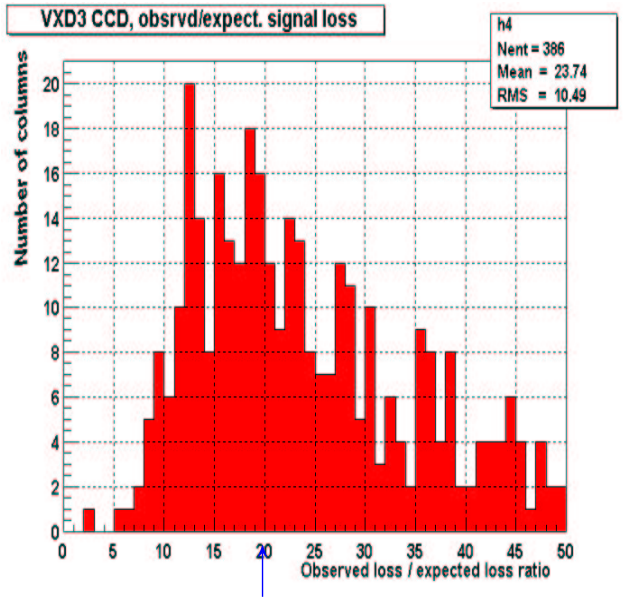

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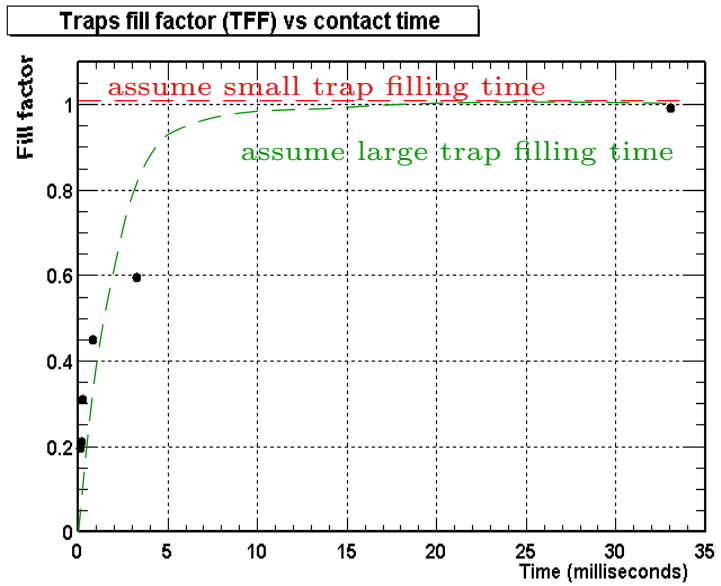
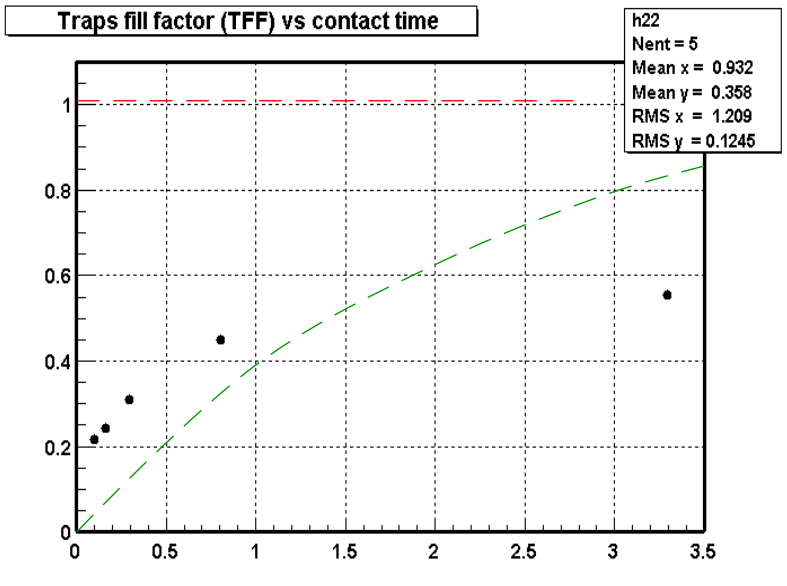
No significant damage due to neutrons is seen in VXD3 data

Observation of slow trap filling

The observed number of traps depends on the delay time during which a charge packet remains within a pixel potential well and it is longer than predicted by theory.

N traps at given time/N traps at 33 ms





same plot, but for time < 3.5 ms

It may result from the extended distribution of the electrons beyond the confinement volume. Only few pixels show very small trap filling time $\rightarrow$ average volume of the trap cluster is larger than traveling charge packet (J. Brau, *et al.*, submitted to Comp.Phys.Comm.).

Conclusions

- The combined study of the damage from neutrons and electrons is performed. Neutrons create clusters of traps while electrons create individual traps distributed uniformly over the surface.

- The study of the SLD VXD3 detectors confirms that the the main damage is due to high energy particles like electrons or photons, while the contribution from neutrons is small.

- Traps filling with signal charge takes noticeable time - much larger that the time signal spend in each pixel. We expect that the increased readout speed will lead to decrease of charge transfer inefficiency.

- The study is to be continued